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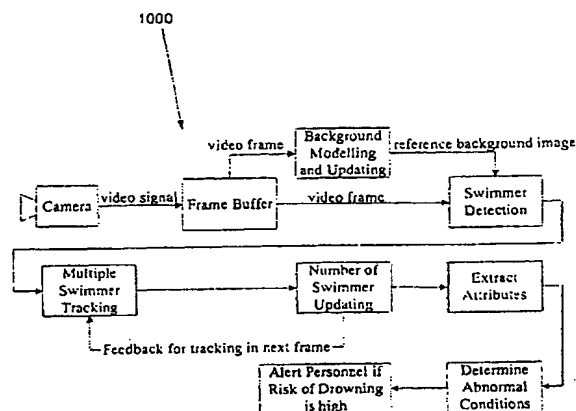
(57) Abstract: This invention describes an audio-visual based method and system for early drowning detection system. In this invention, a number of cameras (100, 200, 201) are mounted on top of a swimming pool (101). These cameras (100, 200, 201) are used to monitor swimmers in the pool (101) together with the aid of an array of microphones (103). Similarly, the microphone array (103) is mounted above the water to cover the entire swimming pool (101). Based on the motion and activity of the swimmer detected through the video camera (100, 200, 201), the swimmer's condition is automatically analyzed. Such automated video analysis includes building the visual background model of the pool (101), detecting the presence of the swimmers in the monitored areas (106), estimating the number of swimmers inside the monitored area (106), tracking the swimmers and analyzing the behaviour of each tracked swimmer in terms of body orientation, moving direction and motion patterns. In addition, the microphone array (103) is deployed to pick up audio signals (104) originating from distress calls. Once the system detects the presence of a potential drowning, both visual and audio alarms will be activated to draw the attention of the person in charge for further confirmation and if necessary to provide necessary follow-up rescue actions.

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Drowning Early Warning System

Background of the invention

5   The present invention relates to an audio-visual system
capable of monitoring a swimming pool and an automated method
of analyzing swimmers' conditions to detect potential
drowning incidents based on the received audio and video
signals. A number of video cameras and an array of
10   microphones are strategically placed above the water around
the pool such that the entire swimming pool can be covered.
Through the processing of the video sequence and/or the audio
signal, abnormal conditions will be detected and considered
as potential drowning cases. Such a system serves as an aid
15   to the life-guards on duty or as a distress call to alert the
attention of nearby people.

At present, there does not exist a viable automated system
that monitors a swimming pool for a person in distress by
20   analyzing swimmers' behavior. However, there are so many
swimming pools worldwide, located in public places, private
houses, condominiums and hotels. Unlike public pools, most
private pools do not have lifeguards on duty. Therefore, a
system that can provide monitoring assistance to such pools
25   would be useful. In addition, a system capable of alerting
the life-guards on duty of potential distress or drowning
incidences would be helpful. Timely rescue of the person in
distress or the drowning victims is critical in saving lives
and in preventing irreversible injuries. It is thus highly
30   desirable to have an automatic system capable of detecting
distress or potential drowning accidents at an early stage.

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Related art

There are a few prior arts describing the monitoring of
swimming pools to detect drowning cases. Most prior arts
5   describe the use of floating devices that will sound an alarm
if there is a wave (US Patent No 3953843, 4510487, 4775854),
an echo (US Patent no 5274607, 5369623) or when the water is
disturbed (US Patent no 3969712 and 5923263). These prior
arts are mainly useful in detecting people entering swimming
10   pools, presumably unauthorized. US Patent No 4747085 and
4932009 describe the use of an array of transducers
(typically ultrasonic) to detect the rate of motion of the
swimmer and if the rate is suspicious, drowning is assumed.
The US Patent No 5043705 describes the use of ultrasonic
15   radar to scan the bottom and top layer of the swimming pool
to detect motionless bodies, assumed to be possible drowning
victims, while US Patent no 5043705 detects motionless bodies
by using sonar scanning upward from the bottom of the pool.
In another approach, US Patent no 5097254, 5408222 and
20   5907281 rely on a device worn by the swimmer. If the swimmer
goes below a certain depth for an extended duration of time,
an alarm will be generated or a float activated. US Patent no
6111510 uses a microphone system to detect heartbeats and
breathing sounds and measures the interval between the
25   absence and presence of these sounds to determine the
possibility of drowning.

The only patents that use video cameras for processing are as
follows:

30

1. 5886630 describes the use of video cameras to detect
motionless bodies at the bottom of a swimming pool. The
presence of such motionless bodies is used as an indication

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of possible drowning.

2.   6133838 describes a method which involves the
installation of multiple underwater cameras at the side of a
5   swimming pool. Drowning is assumed if a body is detected to
be moving slowly or motionless underwater beyond a
predetermined time.

None of them however provides any description of methods of
10   analyzing swimmers' behaviors. Most approaches assumed that
absence of motion or slow motion is an indication of
drowning. There is however a significant possibility that the
actions of standing, swimming on the spot, diving or playing
underwater could trigger false alarms. To reduce such false
15   alarms, the systems above have to be installed sufficiently
deep. In such a case however, distress or the early drowning
of a child at shallower places cannot be detected; moreover
early distress calls by a swimmer and the typical initial
struggles on the water surface before sinking are ignored. By
20   the time the body sinks down to such a depth, there is only
little time left to rescue the victim. Furthermore, the above
systems require the placement of underwater cameras which
requires significant and expensive installation procedures
which also results in an interruption of the pools'
25   operation. Therefore, a system of this type leaves much to be
desired.

Summary of the Invention

30   It is an object of the present invention to provide a system
and method for monitoring a swimming pool to indicate a risk
of drowning of swimmers, which system and method only make
use of above-water video cameras with optional microphones to

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cover a swimming pool and which can reliably indicate a risk
of drowning of swimmers.

The object is achieved by analyzing swimmers' conditions
5   which detects distress or possible drowning cases by making
use of the cues of swimmers' behaviors, such as body
orientation, area of the body above water, moving direction
and motion symmetries, the image features of the surrounding
areas of the swimmers (for example, water ripple patterns),
10   sudden changes in the swimming pattern, irregular activity,
and calls for assistance.

The present invention differs from the existing methods at
least in the following aspects:
15

1.   The system is installed above the water, making
installation and maintenance easy and inexpensive. The
system can be installed in existing swimming pools without
the troublesome and expensive procedures of complete water
20   drainage or costly renovations for cabling and
installation of underwater devices.

2.   The system is monitoring distress and early drowning
signs such as irregular swimming patterns, signs of
25   struggling, sudden submerging of body etc. and calls for
assistance. It does not solely depend on the motionless
cue.

The invention provides a method for monitoring a swimming
30   pool to indicate a risk of drowning of swimmers, the method
comprising:
taking a plurality of subsequent images of a monitoring
region at least partly containing a water surface of water

contained in the swimming pool by means of a camera outside
the water at a plurality of predetermined subsequent moments
in time,

5   in each image, detecting the presence of swimmer image
portions each of which shows a swimmer present in the image,

        processing each detected swimmer image portion, so as to
assign to the respective swimmer image portion a
characteristic two-dimensional geometrical figure, wherein
the geometrical figure is characterized by at least one
10   predetermined geometrical attribute,

        assigning to each geometrical figure a figure position
of the geometrical figure, wherein the figure position
corresponds to a position of the detected swimmer image
portion in the image,

15   for at least one pair of two subsequent images, i.e. of
a presently processed present image and a previously
processed previous image, comparing values of at least one
out of the figure position and the at least one geometrical
attribute of the present image to that of the previous image,
20   so as to detect a change in the figure position/ geometrical
attribute of the present image as compared to the previous
image,

        based on the detected change in the figure position/
geometrical attribute of the subsequent images, assigning to
25   the corresponding swimmer either a drowning condition
indicating that there is a risk of drowning of the swimmer or
a safe condition indicating that there is no risk of drowning
of the swimmer, and

        outputting an output signal if a drowning condition is
30   assigned to the swimmer.

The invention further provides a system for monitoring a
swimming pool, the system comprising:

5

at least one camera being installed for taking a
plurality of images of a monitoring region at least partly
containing a water surface of water contained in the swimming
pool at a plurality of subsequent moments in time, the camera
5   further being installed outside the water, and
a computer being coupled to the camera to receive an
image taken by the camera and being installed to process the
image, wherein the computer comprises:
a means for detecting the presence of swimmer image
10   portions each of which shows a swimmer present in the image,
processing each detected swimmer image portion, so as to
assign to the respective swimmer image portion a
characteristic two-dimensional geometrical figure, wherein
the geometrical figure is characterized by at least one
15   predetermined geometrical attribute,
a means for assigning to each geometrical figure a
figure position of the geometrical figure, wherein the figure
position corresponds to a position of the detected swimmer
image portion in the image,
20   a means for comparing, for at least one pair of two
subsequent images, i.e. of a presently processed present
image and a previously processed previous image, values of at
least one out of the figure position and the at least one
geometrical attribute of the present image to that of the
25   previous image, so as to detect a change in the figure
position/ geometrical attribute of the present image as
compared to the previous image,
a means for assigning to the corresponding swimmer,
based on the detected change in the figure position/
30   geometrical attribute of the subsequent images, either a
drowning condition indicating that there is a risk of
drowning of the swimmer or a safe condition indicating that
there is no risk of drowning of the swimmer, and

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a means for outputting an output signal if a drowning condition is assigned to the swimmer.

Brief discussion of the drawings

5

Fig. 1 shows a system setup for an embodiment of the system according to the present invention;

Fig. 2 illustrates three overlapping images of three
10 different sub-regions of a monitoring region, the images taken by three different cameras;

Fig. 3 shows (a) a typical image of a swimming pool and histograms of the (b) Red, (c) Green and (d) Blue color
15 component of the image;

Fig. 4a shows a background scene of a swimming pool;

Fig. 4b shows a segmentation of the image of Fig. 4a with
20 four clusters;

Fig. 4c shows a 3D (4D) scatter plot of the background scene of Fig. 4a and 4b in RGB color space, where each cluster is shown in different color (gray scale);

25

Fig. 5a shows one time series of intensity values of a pixel where ripples occur, for a plurality of subsequent images (frames);

30 Fig. 5b shows one time series of intensity values of a pixel that the swimmer goes through, for a plurality of subsequent images (frames);

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Fig. 6 (a) to (d) show images of swimmers in a swimming pool, with detected swimmer image portions, wherein the contour of each detected swimmer image portion is approximated by best-fit ellipse;

5

Fig. 7 shows a state flow diagram for the detection of potential drowning;

Fig. 8 shows the orientation of the body of a tracked swimmer

10   for a plurality of subsequent frames taken by a video camera;

Fig. 9 shows the rate of orientation change obtained form Fig. 5; and

15   Fig. 10 shows an illustration of the overall process flow of an embodiment of the system according to the present invention.

Detailed description of the preferred embodiments

20

Hardware Setup

A number of video cameras are mounted above the swimming pool and are located around the pool such that these cameras

25   cover the view of the entire swimming pool. Typically, each camera is mounted high up and at an angle viewing downward to the pool area so as to cover a large field of view, reduce occlusions of swimmers and minimize the perspective foreshortening effects. All the cameras are enclosed in a

30   rain-proof compartment suitable for outdoor setting. Figure 1 shows an example of one such camera 100. There is an overlap in the view of each camera 100 and the two cameras 200, 201 at its side. An example is shown in Figure 2 in

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which 3 video cameras 100, 200, 201 are used to cover the
entire view of the pool 101. The view of camera 100 and
camera 200 overlaps as well as camera 200 and camera 201.

5   These video cameras 100, 200, 201 capture the video
sequences of the activities inside the pool 101. All the
cameras 100, 200, 201 are identical and each is responsible
for monitoring a portion of the pool 101. The video
sequences obtained will be processed by computers 102 to
10 analyze for potential drowning cases.

In the following section, the method of analyzing one
swimmer's behavior is discussed within the context of a
single camera 100, the typical arrangement of which is
15 depicted in Figure 1. Similarly, the array of microphones
103 is located such that sound from any part of the swimming
pool 101 can be picked-up reliably. The audio signal 104
will be enhanced to increase the signal to noise ratio. This
is also depicted in Figure 1.
20
The video signal 105 and audio signal 104 are processed by a
computer 102 or a cluster of computers. The video signal 105
can be sent to a dedicated monitor for viewing by the person
in-charge either via a wired line or a wireless link.
25 Similarly, the audio signal 104 can be sent to the speaker
via either wired or wireless means. When an abnormal
condition is detected, which could possibly be a distress or
drowning incident, the person in-charge will be alerted. The
person in-charge can view the video signal 105 and hear the
30 audio signal 104 to decide whether it is a genuine drowning
incident and if it is, further rescue operation would ensue.
If there is no response from the person in-charge after a
short duration of time, a loud audible sound can be emitted

to alert people nearby the swimming pool 101.

Operating Principle

5   The video data acquired from the video camera 100 is being
      sampled and digitized and the digitized data is made
      available to the computer 102. Typically, the number of
      samples or frames acquired is between 1 to 8 per second. The
      video data being processed is broken into short sequences.
10   Typically, the duration of each sequence is between 20
      seconds to 60 seconds. The operation for each sequence is
      similar and will be as follows.

      For each sequence, a swimmer detection module is launched to
15   detect and count the number of swimmers. This process is
      divided into three stages, namely global statistical model
      generation, segmentation of swimmers and updating the
      statistical model. These will be described in more detail
      below.
20

      1. Global statistical model generation

      Figure 3 shows the histogram 300 of a background scene of a
      typical swimming pool 101 in RGB (red, green, and blue)
25   color space. These data display the behavior as expected:
      the black strip and water pixels form two fairly well
      defined peaks. This observation inspired us to employ the
      kernel-based mean shift procedure [1] to perform mean shift
      clustering. It provides a mixture of Gaussian distribution
30   for the background scene.

      The uniqueness of background scene of swimming pool 101 in a
      data analysis context lies in the fact that the image data

                                    10

are strongly correlated. Clusters in the joint domain correspond to underlying contiguous regions within the image, the recovery of which has been achieved using the mean shift procedure. Figure 4 shows the 3D scatter plot 402

5   of the scene 400 of the swimming pool 101 in the RGB color space and its segmentation 401. The image data are assigned to clusters using Euclidean distance. Each cluster is assumed to be a multivariate Gaussian characterized by its mean value and covariance matrix.

10

2. Segmentation of swimmers

Swimmers in the scene are characterized by a relatively large deviation from the background statistics. Changes in

15   the model scene are computed at every frame by comparing current frames with the model. With the set of N clusters $\{C_i\}_{i=1...N}$ that model the background scene at time t, a similarity measure is computed between the incoming frame and the background using the normalized Mahalanobis

20   distance. This provides an estimate of the similarity with the background at every pixel. The distance measure of a pixel in the current frame is:

$$D_p\ (X_t)\ =arg\ min\ (D_p\ (X_t \setminus C_i : i =1...N)),$$

25 i

$$D_p\ (X_t \setminus C_i\ )=\ In\ |\Sigma_{i,t}|+\ (\ X_t -\ \mu_{i,t}\ )^T\ \Sigma^{-1}_{i,t}\ (\ X_t -\ \mu_{i,t}\ ),$$

Where $D_p\ (X_t)$ measures the lowest difference between a cluster centroid and the projection of the pixel's observed

30   value on the sub-space spanned by the cluster; $\mu_{i,t}$ and $\Sigma_{i,t}$ are the mean value and covariance matrix of the ith cluster at time t.

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Thus, if a region of the image is sufficiently dissimilar from the modeled background, the system will consider it to be a swimmer. A binary map is then formed for the current frame, in which regions corresponding to the swimmers are

5   highlighted as motion blobs. Basic morphological operations (erosion-dilation) [2] are applied to remove small noise regions and to fill holes in these regions of interest. However, some segmentation errors will still persist due to reflections (or ripples) on the surface of the water, which

10   are not explicitly included into the background model. By including a-priori knowledge of the swimmers, our system is able to further suppress this type of false segmentation.

     In order to differentiate reflections on the surface of

15   water and swimmers, we take a time series of intensity values for two types of pixels. One type of pixels has the occurrence of reflections only (with no swimmers, compare first time series 500) while swimmers pass through the other type of pixels, compare second time series 501. Figure 5

20   shows the typical time series 500, 501 of these two types of pixels. Clearly, there is a distinctive contrast between swimmers and reflections in term of intensity changes. Swimmers generally cause a significant decrease in intensity of the background scene, while reflections and/or ripples

25   make the scene brighter. As the pool 101 mainly contains water, the overall brightness of the scene B_s can be obtained from the mean value of the cluster having the largest sample size. We then impost another constraint on the segmentation of the swimmers: $B_s - I_t > T_B$, where I_t is the brightness of

30   the pixel in the current frame and T_B is the conveniently chosen threshold. The binary map in which foreground regions contains the swimmers is represented by:

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$$b_i \ (t) \ = U\{ \ [D_p \ (X_t \ ) \ > \Gamma \ ] \wedge \ [B_s \ - \ I_t \ > T_B] \}.$$

where $\wedge$ denotes the logical 'AND' operator. Thus, the binary
map for the frame at time t is defined by the locations
where the difference from the background model is greater
than a given threshold Γ and the brightness level is lower
than the overall brightness of the pool by the threshold T_B.

3. Updating the background global statistical model

Since our background model gives the global description of
the background scene, the update of the model mainly caters
for the changes in overall lighting condition. For each
frame considered, the existing Gaussian clusters for the
background model are updated with the color values of pixels
that are not classified as swimmers. The background pixels
are assigned to the respective nearest clusters according to
the normalized Mahalanobis distance.

The parameters $\mu_{i,t}$ and $\Sigma_{i,t}$ of ith cluster which matches the
set of N new samples $\{X_K\}$ are updated as follows:

$$\mu_{i,t} = (1 - \rho)\mu_{i,t-1} + \rho \overline{X}_{i,t}$$

$$\Sigma_{i,t} = (1 - \rho) \ \Sigma_{i,t-1} + \rho C_{i,t}$$

where

$$\overline{X}_{i,t} = \frac{1}{N} \sum_{k=1}^{N} X_k \ ;$$

$$C_{i,t} = \frac{1}{N} \sum_{k=1}^{N} (X_k - \overline{X}_{i,t})(X_k - \overline{X}_{i,t})^T \ ,$$

and ρ is the learning factor for adapting current

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distribution of ith cluster. In our implementation, the learning factor is a constant to provide faster Gaussian tracking at some expense of accuracy.

5   At the end of this segmentation module, the system represents each of the detected swimmer with a set of attributes, including an identity label, size, colour, centroid position and major orientation of the segmented swimmer represented by the major and minor axes of a best-
10 fit ellipse 600 to 603 around the swimmer. Figure 6 shows detected swimmers in a swimming pool 101 with the superimposed best-fit ellipses 600 to 603.

This entire detection and tracking process is summarized as
15 follows:

1. Convert the original RGB color space into the HSV color space.

20 2. Determine the area of interest to monitor 106 (water area) during system setup.

3. Compute a global statistical model to represent the background of the swimming pool 101. During system setup,
25 an estimated background scene 400 to 402 for the swimming pool 101 is computed by observing the empty pool without any swimmer for some time, and pre-stored.

4. Detect swimmers by locating regions with large
30 deviation from the background global statistical model.

5. Apply a series of morphological erosion and dilation operations [2] to remove isolated noise pixels obtained

above.

6.   Connect the changed pixels into a contiguous
foreground region, called blobs, using the connected
component analysis algorithm [2].

7.   Update the background global statistical model.

8.   Enclose each newly detected blob with a best-fit
ellipse 600 to 603;

9.   Label and count the blobs inside the monitored area.

After the swimmers are detected, the swimmers will be
tracked using a multi-swimmer tracking module. This module
uses a Kalman filter based multiple hypotheses tracking
algorithm that incorporates color, position and size as the
matching features. The system initiates a Kalman model for
each detected swimmer. At each frame, an available pool of
Kalman models are used to identify the detected swimmers
with respect to the previously detected swimmers in the
previous frame (this process is called correspondence). When
unambiguous correspondence between a model and a swimmer can
be established, the model will be updated using the latest
information of that swimmer. Models that cannot be used to
explain any detected swimmer within a certain period will be
removed. In that case, the system assumes swimmers
corresponding to those models have left the monitored area.

The multi-swimmer tracking process is as follows:

1.   A region corresponding to the pool area will be
designated in each view of the video camera 100 so that

the computer 102 can easily know the area of interest
(AOI) (monitoring region 106) to monitor. This will be
done only once during system setup;

5   2.   The tracking module will monitor for swimmers entering
into the AOI (monitoring region 106);

3.   From the blobs detected using the above method,
attributes of the swimmers such as the position and
10   velocity will be extracted to form a tracking attribute
vector, a. For example, if the tracking attributes used
are position, p, and velocity, v, then the vector a for
swimmer i will be in the form:

$$a_i = (p_i, v_i)$$

15

4.   Compute the matching score matrix, M. Each entry s_{ij}
in M is the inverse weighted sum of the Euclidean
distance, D_{ij} between the ith blob's tracking attribute
vector, a_i, in the current frame and the jth swimmer's
20   tracking attribute vector, a_j, in previous frame and the
Euclidean distance $\overline{D}_{ij}$ of a_i in the current frame and the
predicted tracking attribute vector, $\overline{a}_j$, of the jth
swimmer. Therefore, the matrix, M, measures the likelihood
of blobs in the current frame corresponding to swimmers in
25   previous frame. Assuming that there are m swimmers in the
current frame and n swimmers in the previous frame, then
the matrix M will have the form:

$$
M = \begin{bmatrix} S_{11} & S_{21} & \cdots & \cdots & S_{m1} \\ S_{12} & \ddots & & & \vdots \\ \vdots & & \ddots & & \vdots \\ \vdots & & & \ddots & \vdots \\ S_{1n} & \cdots & \cdots & \cdots & S_{mn} \end{bmatrix},
$$

where

$$
s_{ij} = \frac{1}{D_{ij} + \overline{D}_{ij}},
$$

$D_{ij} = \| a_i - a_j \|$, and $\overline{D}_{ij} = \| a_i - \bar{a}_j \|$, with

$\| x \|$ denotes Euclidean norm of x ,

$i = 1 \dots m$ and $j = 1 \dots n$.

5.   Establish the one-to-one correspondence of swimmers
between the current and previous frames by obtaining the
scalar product of two matrices M_1 and M_2, both of which are
derived from the matching score matrix, M. M_1 have entries
equal to 1 corresponding to the highest blob-to-swimmer
matching scores and other entries equal to 0 for the
current frame while similarly, M_2 have entries equal to 1
corresponding to the highest swimmer-to-blob matching
scores and other entries equal to 0 for the previous
frame. The scalar product of M_1 and M_2 creates a matrix M_3,
whose nonzero entries indicate the unambiguous
correspondences between swimmers;

6.   Analyze the locations of any unmatched blobs. If it is
sufficiently close to one of the existing swimmers and
appear away from the boundary of the AOI then the
unmatched blob will be merged into the nearest swimmer.
Otherwise, the unmatched blob will be added to the list of
newly appearing swimmers if the system manages to track

them over a few frames. If the new blob disappears after a
few frames, then the new blob will be considered as noise
and will be dropped;

5   7.   Feed the blob's information into a Kalman filter [3]
to obtain the swimmer's predicted attributes for the next
frame.

Once the swimmers are successfully tracked, the multiple-
10   swimmer tracking module will extract the attributes of the
tracked swimmers. For each swimmer, multiple attributes are
extracted, such as the spatial location of the centroid of
the swimmer, body orientation and size. From the temporal
sequence of these attributes, other attributes such as the
15   rate of orientation change, moving directions, motion
symmetry, regularity of motion, sudden change in swimming
pattern and water ripple patterns can be obtained. By
learning the temporal model of these attributes, the system
will compute an overall score for each swimmer to determine
20   whether the swimmer is normal or at risk of drowning
(including cases of distress and early drowning).

The analysis process of the temporal model is based on the
optimal filtering of past measurements. The state flow
25   diagram 700 of the detection of potential drowning is given
in Figure 7. The system will consider the swimmer to be in an
abnormal condition if the system fails to give good
prediction of the swimmer's attributes. This is illustrated
using the rate of orientation change of the swimmer's body as
30   an example. A sample plot 800 is shown in Figure 8. As can be
seen, starting from around Frame 350, the body orientation of
the swimmer changes much faster and is irregular. The fast
and irregular change in body orientation serves as an

18

indication to the breach of predictability of the swimming pattern. Figure 9 shows the rate of orientation change 900. This plot 900 is obtained from Figure 8 using the following equation:

5    $r(t) = \dfrac{\sum\limits_{i=1}^{T} |\theta_i - \theta_{i+1}|}{T - 1}$, where T is the preset length of temporal

window.

Once the rate of orientation change 900 is larger than a preset threshold, the system will not be able to accurately predict the body orientation in the new frame using prior

10   measurements. Therefore, a breach of predictability of the swimming pattern is detected in this case, and becomes one possible good indicator of an abnormal condition. The occurrence of several abnormal conditions together would be a good indication of a swimmer at risk of drowning.

15

The extraction of relevant features and their interpretation is most crucial for automatic detection of swimmers at risk of drowning. These features are an important aspect of this invention and besides the rate of change of orientation 900

20   described above, other features will now be described in more detail:

a)   forward motion of the swimmer;

25   This attribute considers a swimmer to be in an abnormal condition if the swimmer is not moving forward but there is detected movement of the arms. This attribute is characterized by the spatial location of the centroid of the swimmer not changing beyond a preset boundary, given

30   by:

19

$$\| v_c - v_p \| \le D_{min}, \text{ where}$$

v_c = spatial location of centroid at current frame

v_p = spatial location of centroid at previous frame

5      $v_i = (x_i, y_i)$, with the x, y coordinates in the image

D_{min} = threshold of the change to consider as not moving

forward.

The rate of motion will also be considered. An abnormal

10   condition arises if the motion slows to almost a halt.

b)   posture of the swimmer, whether upright or just slightly

leaning;

15   This attribute considers a swimmer to be in a

potentially abnormal condition if the posture of the

body is upright. This is characterized by the major axis

of the ellipse 600 to 603 being vertical or close to

vertical.

20

c)   size of the swimmer's body above the water;

This attribute considers a swimmer to be in a

potentially abnormal condition if the size of the body,

25   inclusive of the head that is not submerged in the

water, is reducing or that increase in size is not

detected for a period of time. This feature can be

characterized by the change in the area of the best-fit

ellipse 600 to 603.

30

d)   path of the swimmer's movement;

This attribute considers a swimmer to be in a

potentially abnormal condition if there is a significant change in the path taken by the swimmer as predicted from the past frames. If the body is in an upright position, the path to be checked could include up-down

5   movement. The path can be obtained from the plot of the centroid over time. The best fit curve of the plot gives the path taken by the swimmer and the deviation of the path is seen as a change in the best fit curve or the presence of a deflection point.

10

    e)   motion symmetry of the swimmer;

This attribute considers a swimmer to be in a potentially abnormal condition if the motion of the

15   swimmer does not show any symmetry. An example in which this attribute can be obtained is by dividing the image into two along the major axis of the ellipse 600 to 603, then flip one of the images along the axis and compute the correlation [2] between the two. If the value of the

20   correlation is small, then there isn't much symmetry of the motion of the swimmer.

    f)   periodicity or repeatability of the swimmer's movement pattern;

25

This attribute considers a swimmer to be in a potentially abnormal condition if the motion of the swimmer does not show any periodic or repeatable pattern. An example where this attribute can be obtained

30   is by normalizing the image extracted from the best-fit ellipse 600 to 603 and then computing the cross-correlation [2] of these images over different frames. If the value of the correlation is smaller than a

predetermined threshold, then no repeatability of the
motion is detected.

g)   ripple pattern in the surrounding area of the
5   swimmer;

This attribute considers a swimmer to be in a
potentially abnormal condition if the ripple surrounding
the swimmer is more violent than normal. This attribute
10   is characterized by the overall brightness of the water
surrounding the swimmer. If the overall brightness
increases beyond a certain threshold over the average of
the water, then abnormal ripple is considered present.

15   In all the above indicators, the presence of several abnormal
conditions together will serve as an indication of a swimmer
at risk of drowning. For example, one of the considerations
is that if the body orientation is vertical and there is no
forward motion and that the motion is not symmetrical, then
20   the swimmer is considered at risk of drowning. Once such
condition is detected, the person in charge will be alerted
and the video signal 105 and audio signal 104 corresponding
to the area of the swimmer will be made available to the
person in charge. Figure 10 shows the overall process flow
25   1000 of the proposed system.

Summarizing, this invention describes an audio-visual based
method and system for early drowning detection system. In
this invention, a number of cameras 100, 200, 201 are
30   mounted on top of a swimming pool 101. These cameras 100,
200, 201 are used to monitor swimmers in the pool 101
together with the aid of an array of microphones 103.
Similarly, the microphone array 103 is mounted above the

water to cover the entire swimming pool 101. Based on the
motion and activity of the swimmer detected through the
video camera 100, 200, 201, the swimmer's condition is
automatically analyzed. Such automated video analysis
5   includes building the visual background model of the pool
101, detecting the presence of swimmers in the monitored
areas 106, estimating the number of swimmers inside the
monitored area 106, tracking the swimmers and analyzing the
behavior of each tracked swimmer in terms of body
10   orientation, moving direction and motion patterns. In
addition, the microphone array 103 is deployed to pick up
audio signals 104 originating from distress calls. Once the
system detects the presence of a potential drowning, both
visual and audio alarms will be activated to draw the
15   attention of the person in charge for further confirmation
and if necessary to provide necessary follow-up rescue
actions.

List of reference signs

100 video camera

101 swimming pool

5   102 computer

103 microphone

104 audio signal

105 video signal

106 monitored area of interest

10   200 video camera

201 video camera

300 histogram

400 background scene

401 segmentation

15   402 3D scatter plot

500 first time series

501 second time series

600 best-fit ellipse

601 best-fit ellipse

20   602 best-fit ellipse

603 best-fit ellipse

700 state flow diagram

800 sample plot

900 plot showing the rate of orientation change

25   1000 overall process flow

References

1. Yizong Cheng, "Mean Shift, Mode Seeking and Clustering," IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 17, No. 8, 1995, pp. 790-799.

2. Anil K. Jain, "Fundamentals of Digital Image Processing", Prentice Hall, 1989.

3. Yaakov Bar-Shalom & Xiao-Rong Li, Estimation and Tracking: Principles, Techniques and Software" Artech House, 1993.

Claims

1.   A method for monitoring a swimming pool (101) to
indicate a risk of drowning of swimmers, the method
5   comprising:
taking a plurality of subsequent images of a monitoring
region (106) at least partly containing a water surface of
water contained in the swimming pool (101) by means of a
camera (100) outside the water at a plurality of
10   predetermined subsequent moments in time,
in each image, detecting the presence of swimmer image
portions each of which shows a swimmer present in the image,
processing each detected swimmer image portion, so as to
assign to the respective swimmer image portion a
15   characteristic two-dimensional geometrical figure, wherein
the geometrical figure characterizes at least one geometrical
attribute,
assigning to each geometrical figure a figure position
of the geometrical figure, wherein the figure position
20   corresponds to a position of the detected swimmer image
portion in the image,
for at least one pair of two subsequent images, i.e. of
a presently processed present image and a previously
processed previous image, comparing values of at least one
25   out of the figure position and the at least one geometrical
attribute of the present image to that of the previous image,
so as to detect a change in the figure position/ geometrical
attribute of the present image as compared to the previous
image,
30 .   based on the detected change in the figure position/
geometrical attribute of the subsequent images, assigning to
the corresponding swimmer either a drowning condition
indicating that there is a risk of drowning of the swimmer or

26

a safe condition indicating that there is no risk of drowning
of the swimmer, and

outputting an output signal if à drowning condition is
assigned to the swimmer.

5

2.   The method according to claim 1, wherein the at least
one geometrical attribute comprises at least one attribute
out of:

a two-dimensional area of the geometrical figure

10   corresponding to an area of the corresponding swimmer's body
visible to the camera (100),

a shape of the geometrical figure corresponding to an
approximate contour of the corresponding swimmer's body
visible to the camera (100),

15   an orientation of an axis of the geometrical figure,
corresponding to an orientation of an axis of the
corresponding swimmer's body visible to the camera (100),

a length of an axis of the geometrical figure,
corresponding to a length or width of the corresponding

20   swimmer's body visible to the camera (100), and

a symmetry condition of the geometrical figure.

3.   The method according to claim 1,
wherein the characteristic two-dimensional geometrical

25   figure is a best-fit ellipse (600 to 603) by which a contour
of the respective swimmer image portion is approximated, a
major axis, a minor axis and a centroid (center) of the best-
fit ellipse (600 to 603) are adjusted to best approximate
said contour of the swimmer.

30

4.   The method according to claim 3, wherein the at least
one geometrical attribute comprises at least one attribute
out of:

27

an area of the best-fit ellipse (600 to 603),

an orientation of the major axis of the best-fit ellipse (600 to 603),

an orientation of the minor axis of the best-fit ellipse

5   (600 to 603),

a length of the major axis of the best-fit ellipse (600 to 603),

a length of the minor axis of the best-fit ellipse (600 to 603),

10 a symmetry of the swimmer's body visible to the camera (100) with respect to the major axis of the best-fit ellipse (600 to 603), and

a symmetry of the swimmer's body visible to the camera (100) with respect to the minor axis of the best-fit ellipse

15 (600 to 603).

5.   The method according to claim 1, further comprising:

for each image, forming a binary map of the image, wherein each detected swimmer image portion is represented by

20 a highlighted blob in the binary map and wherein the surface image portion is represented by dark regions in the binary map.

6.   The method according to claim 1,

25 wherein the images are video frames taken over a predetermined length of time by means of a video camera (100).

7.   The method according to claim 1, wherein

30 a moving velocity of the figure position corresponding to a moving velocity of corresponding swimmer is determined from the detected change in the figure position and

a possible drowning condition is assigned to the swimmer
if moving velocity of the figure position is lower than a
predetermined moving velocity threshold.

5   8.   The method according to claim 2, wherein
        a possible drowning condition is assigned to the swimmer
if the orientation of the axis of the swimmer's body is
vertical for a predetermined certain number out of a
predetermined total number of subsequent images or that the
10 rate of change of the orientation (900) is higher than a
predetermined threshold for the rate of orientation change
(900).

    9.   The method according to claim 2, wherein
15   a possible drowning condition is assigned to the swimmer
if the detected area of the geometrical figure is lower than
a predetermined area threshold for a predetermined certain
number out of a predetermined total number of subsequent
images.
20
    10. The method according to claim 1, wherein
        a movement path of the figure position corresponding to
a movement path of the corresponding swimmer is determined
from the detected change in the figure position of a
25 plurality of subsequent images and
        a possible drowning condition is assigned to the swimmer
if the movement path of the figure position shows at least
one deviation from an expected normal feature obtained by
predicting the movement path.
30
    11. The method according to claim 1, wherein
        a movement periodicity of the geometrical figure
corresponding to a movement periodicity of corresponding

29

swimmer is determined from the detected change in the figure position and/or at least one geometrical attribute of a plurality of subsequent images and/or repeatable pattern of the swimmer's body visible to the camera (100) and

5   a drowning condition is assigned to the swimmer if the movement periodicity of the figure position shows at least one predetermined abnormal feature.

12.   The method according to claim 1, further comprising:

10   assigning to each geometrical figure a surrounding area of the geometrical figure corresponding to an area of water surrounding the corresponding swimmer, and

        assigning to the swimmer a drowning condition if the surrounding area shows at least one predetermined abnormal

15   feature.

13.   The method according to claim 1,
        further comprising labeling each assigned geometrical figure, so as to distinguish different underlying swimmers.

20

14.   The method according to claim 1, further comprising counting the number of assigned geometrical figures.

15.   The method according to claim 1,

25   wherein a present assigned geometrical figure of a present image is assigned to a predetermined swimmer, and wherein a subsequent assigned geometrical figure of a subsequent image is assigned to the identical predetermined swimmer if the figure position of the subsequent assigned

30   geometrical figure is sufficiently close to the corresponding figure position of the present assigned geometrical figure.

16.   The method according to claim 15,

wherein the predetermined swimmer is deemed to have left
the monitoring region if, for a predetermined number of
subsequent images, no subsequent assigned geometrical figure
having a figure position which is sufficiently close to the
5   corresponding figure position of the respective present
assigned geometrical figure can be found.

17.   The method according to claim 1, further comprising
providing a gauge global statistical model of the swimming
10   pool (101), the gauge global statistical model comprising at
least a water surface model characteristic of the water, and
wherein detecting the presence of swimmer image portions
comprises:
        by processing of the image, generating a current global
15   statistical model, the current global statistical model
comprising at least a water surface model characterizing a
surface image portion comprising the water surface and, if at
least one swimmer is present in the image, at least one
swimmer model characterizing at least one swimmer image
20   portion comprising at least one swimmer,
        identifying the at least one swimmer model by a
comparison of the current global statistical model to the
gauge global statistical model, so as to detect the presence
of at least one swimmer image portion.
25
18.   The method according to claim 17, wherein the gauge
global statistical model is generated from a previously
processed image.

30   19.   The method according to claim 17, wherein the gauge
global statistical model is generated from an image taken of
the swimming pool (101) not containing any swimmers.

31

20.   The method according to claim 17, further comprising:

    updating the gauge global statistical model by the current global statistical model, ignoring the swimmer model if any is present.

5

21.   The method according to claim 17,

    wherein any surface image portion has mainly or in average a surface color and the at least one swimmer image portion has mainly or in average a swimmer color, and

10   wherein the generating of the global statistical model comprises:

    for a predetermined plurality of moments out of the subsequent moments in time, converting respectively at least one image into a color-distribution in a four-dimensional

15   color space spanned up by three primary colors and an brightness, wherein any surface image portion is converted into a surface cluster representing the surface color, and wherein any swimmer image portion is converted into a swimmer cluster representing the swimmer color,

20   the converting of the image being performed by generating a histogram (300) of the image in each of the three primary colors, wherein each histogram (300) indicates the frequency distribution of the image of the swimming pool (101) in the respective primary color, and

25   the brightness at each point in said color space being equal to a distance computed from the three frequencies of occurrence in the three primary colors at the respective point.

30   22.   The method according to claim 21,

    wherein the distance measure is computed using the Euclidian distance.

32

23.   The method according to claim 21,
      wherein the color space is the RGB color space.

24.   The method according to claim 21, wherein the color
5   space is the HSV color space.

25.   The method according to claim 21, wherein the at least
one swimmer image portion is detected in that the swimmer
color deviates from the surface color.

10
26.   The method according to claim 21, further comprising:
      assigning to each geometrical figure a surrounding area
of the geometrical figure corresponding to an area of water
surrounding the corresponding swimmer, and
15   assigning to the swimmer a drowning condition if the
surrounding area shows a color which is sufficiently
different from the swimmer color and which is sufficiently
different from the surface color.

20   27.   The method according to claim 21, further comprising:
      after detecting the presence of swimmer image portions
in a present image and before detecting the presence of
swimmer image portions in a subsequent image, updating the
water surface model of the gauge global statistical model by
25   the water surface model of the current global statistical
model of the present image.

28.   The method according to claim 21,
      wherein the detecting of the swimmer model is performed
30   by computing a difference measure between the current global
statistical model and the gauge global statistical model,
wherein the swimmer model is identified if the difference
measure is larger than a predetermined difference threshold.

29.   The method according to claim 28,

wherein the similarity measure is computed using the
normalized Mahalanobis distance.

5

30.   The method according to claim 21,

wherein the images are video frames taken over a
predetermined length of time by means of a video camera (100)
and wherein a sequence of several subsequent video frames is
10   used in generating the respective color distribution.

31.   A system for monitoring a swimming pool (101), the
system comprising:

at least one camera (100) being installed for taking a
15   plurality of images of a monitoring region (106) at least
partly containing a water surface of water contained in the
swimming pool (101) at a plurality of subsequent moments in
time, the camera (100) further being installed outside the
water, and
20   a computer (102) being coupled to the camera (100) to
receive an image taken by the camera (100) and being
installed to process the image, wherein the computer (102)
comprises:

a means for detecting the presence of swimmer image
25   portions each of which shows a swimmer present in the image,
processing each detected swimmer image portion, so as to
assign to the respective swimmer image portion a
characteristic two-dimensional geometrical figure, wherein
the geometrical figure characterizes at least one geometrical
30   attribute,

a means for assigning to each geometrical figure a
figure position of the geometrical figure, wherein the figure

34

position corresponds to a position of the detected swimmer
image portion in the image,

        a means for comparing, for at least one pair of two
subsequent images, i.e. of a presently processed present
5   image and a previously processed previous image, values of at
least one out of the figure position and the at least one
geometrical attribute of the present image to that of the
previous image, so as to detect a change in the figure
position/ geometrical attribute of the present image as
10 compared to the previous image,

        a means for assigning to the corresponding swimmer,
based on the detected change in the figure position/
geometrical attribute of the subsequent images, either a
drowning condition indicating that there is a risk of
15 drowning of the swimmer or a safe condition indicating that
there is no risk of drowning of the swimmer, and

        a means for outputting an output signal if a
drowning condition is assigned to the swimmer.

20 32. The system according to claim 31,
        further comprising a display means being coupled to the
computer (102) for displaying a display signal which is
dependent on the output signal.

25 33. The system according to claim 32,
        wherein the display means is an alarm means and wherein
the display signal is a signal which is suited for driving
the alarm means.

30 34. The system according to claim 32,
        wherein the display means is a computer monitor and
wherein the display signal is a signal which is suited for
being displayed on the computer monitor.

35

35. The system according to claim 31,

wherein a plurality of cameras (100, 200, 201) is
provided as the at least one camera (100, 200, 201), wherein
5   each camera (100, 200, 201) is installed for taking a
plurality of images of a predetermined sub-region of the
monitoring region at subsequent moments in time, wherein
images of different sub-regions are taken by different
cameras (100, 200, 201).
10

36. The system according to claim 35,

wherein adjacent sub-regions partly overlap.

37. The system according to claim 31,
15   further comprising at least one microphone (103) for
detecting sounds such as distress calls from swimmers.

38. A system for monitoring a swimming pool (101), the
system comprising:
20   at least one camera (100) being installed for taking a
plurality of images of a monitoring region (106) at least
partly containing a water surface of water contained in the
swimming pool (101) at a plurality of subsequent moments in
time, the camera (100) further being installed outside the
25   water, and
         a computer (102) being coupled to the camera (100) to
receive an image taken by the camera (100) and being
installed to process the image, wherein the computer (102)
comprises:
30   a means for detecting the presence of swimmer image
portions each of which shows a swimmer present in the image,
processing each detected swimmer image portion, so as to
assign to the respective swimmer image portion a

36

characteristic two-dimensional geometrical figure, wherein
the geometrical figure characterizes at least one geometrical
attribute,

5   a means for assigning to each geometrical figure a
figure position of the geometrical figure, wherein the figure
position corresponds to a position of the detected swimmer
image portion in the image,

           a means for comparing, for at least one pair of two
subsequent images, i.e. of a presently processed present
10   image and a previously processed previous image, values of at
least one out of the figure position and the at least one
geometrical attribute of the present image to that of the
previous image, so as to detect a change in the figure
position/ geometrical attribute of the present image as
15   compared to the previous image,

           a means for assigning to the corresponding swimmer,
based on the detected change in the figure position/
geometrical attribute of the subsequent images, either a
drowning condition indicating that there is a risk of
20   drowning of the swimmer or a safe condition indicating that
there is no risk of drowning of the swimmer, and

           a means for outputting an output signal if a
drowning condition is assigned to the swimmer,

25   wherein the means for detecting the presence of swimmer image
portions comprises:

           a means for generating a global statistic model
from a taken image,

           a storage means for storing global statistic
30   models, and

           a comparison means for comparing a current global
statistic model to a gauge global statistic model which is
stored in the storing means.

39. The method according to claim 1, further comprising the
step of differentiating a swimmer from ripples on the surface
of the water based on contrast information.

5

40. The system according to claim 31 or 38, further
comprising means for differentiating a swimmer from ripples
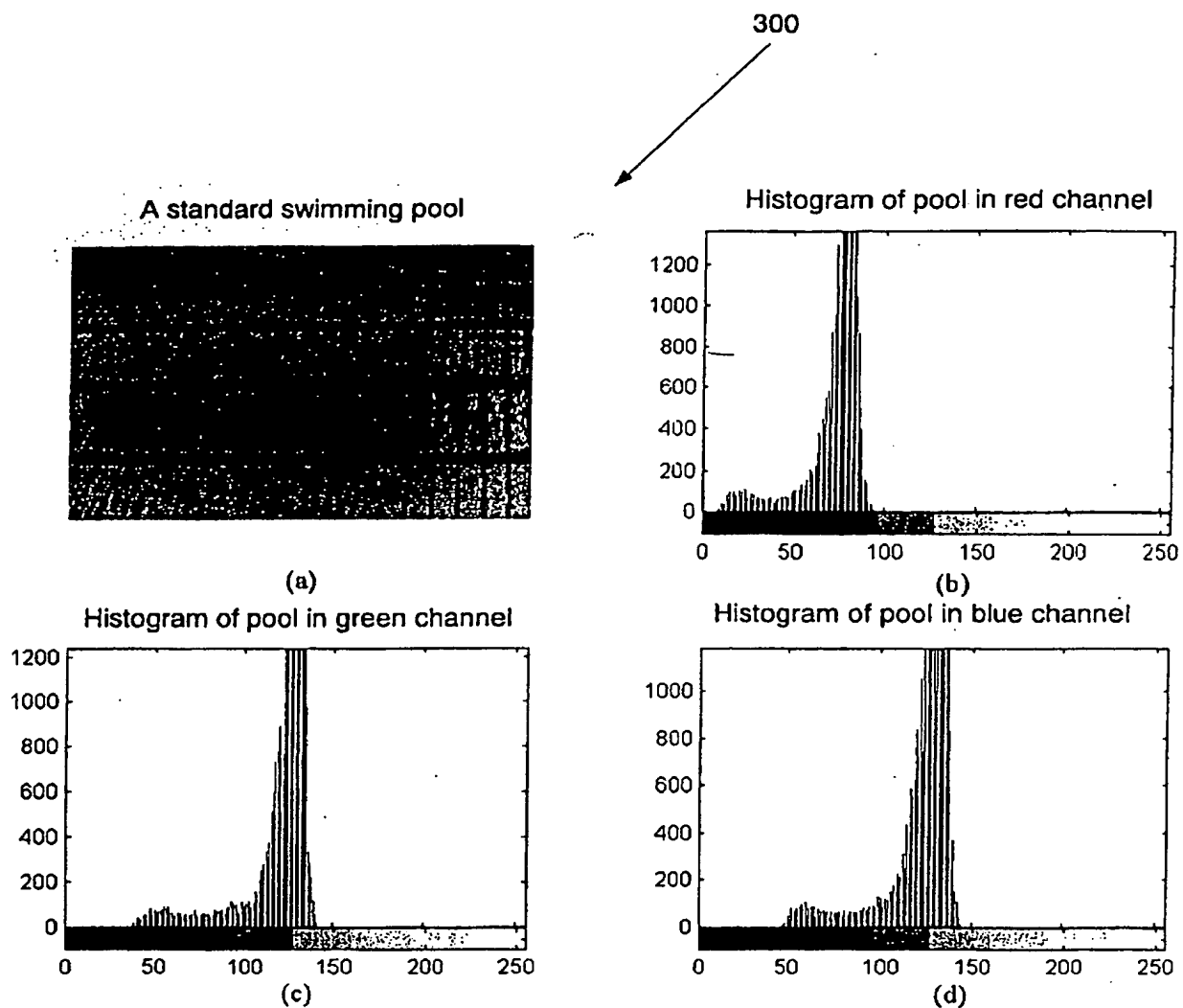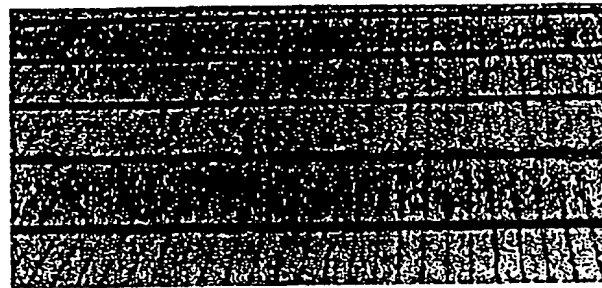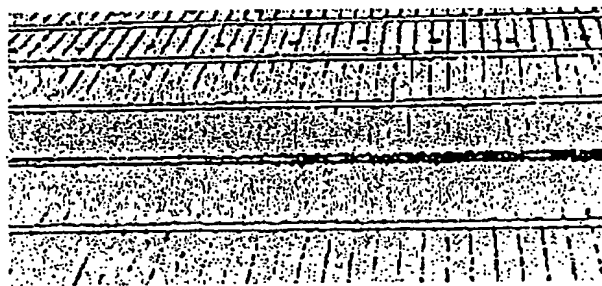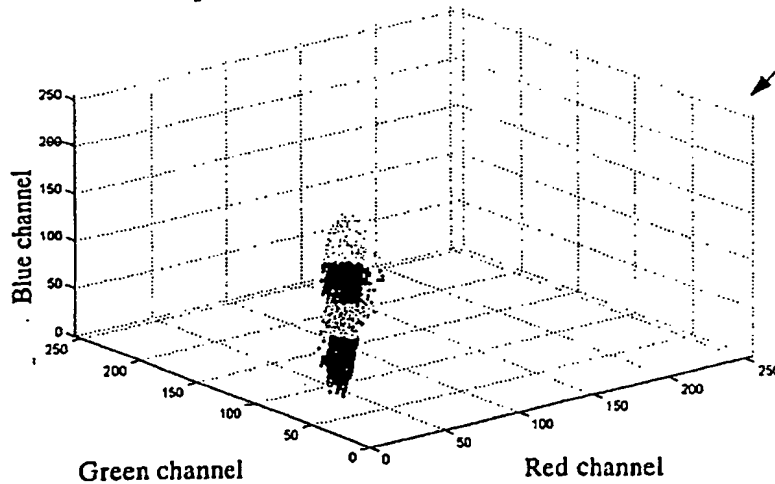on the surface of the water based on contrast information.

10

Figure 1

Camera 1   Camera 2   Camera 3

Figure 2

300

A standard swimming pool   Histogram of pool in red channel

(a)   (b)

Histogram of pool in green channel   Histogram of pool in blue channel

(c)   (d)

Figure 3

(a)
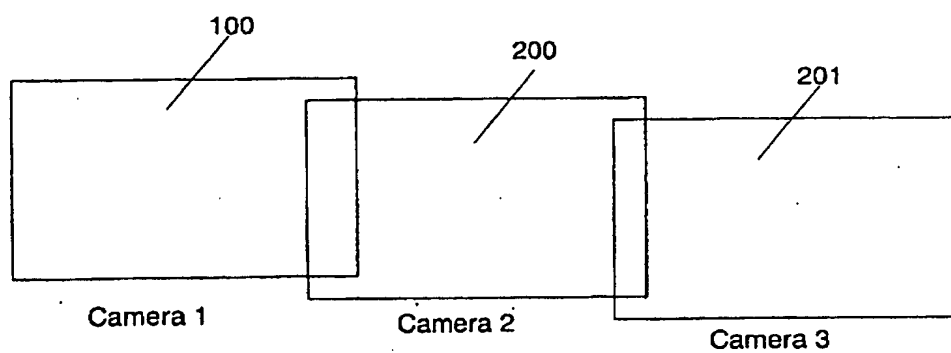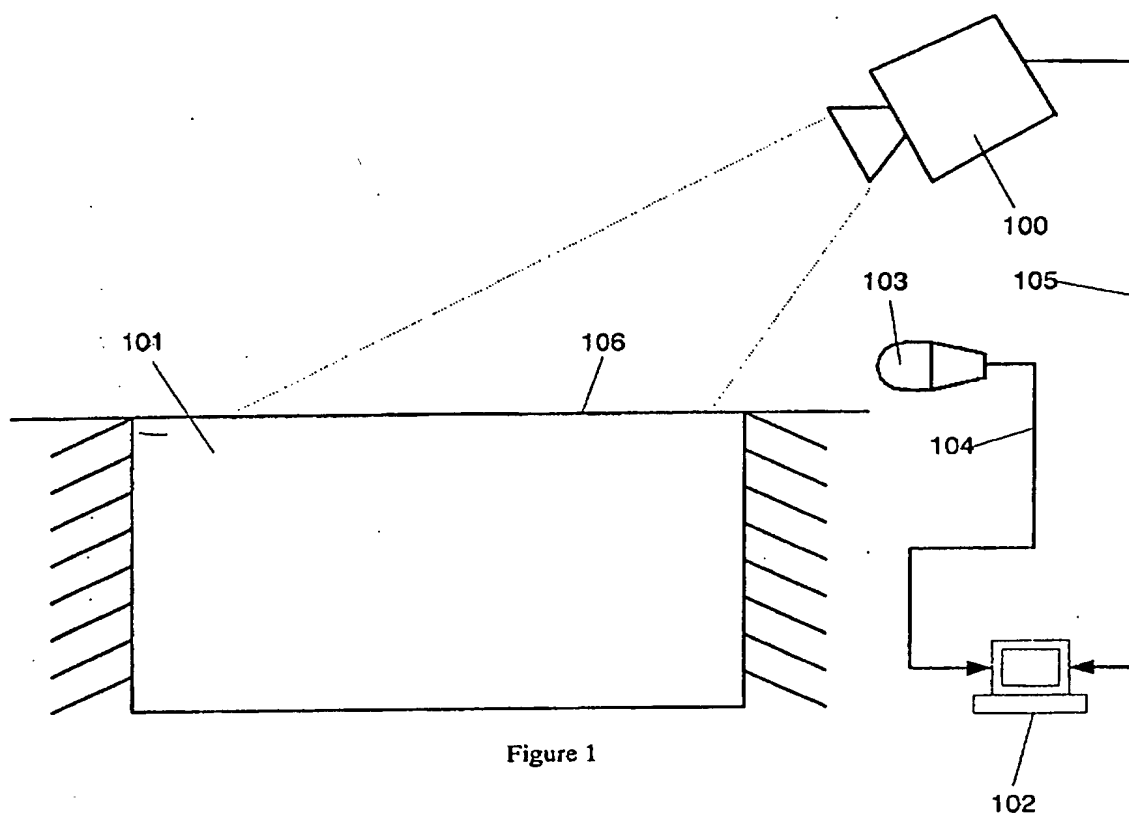
(b)

3D scatter plot of background scene of the swimming pool

☐ : ripples
■ : water
▨ : black strips
■ : lanes

(c)

Figure 4

Figure 5

Figure 6

700

Figure 7

800

Figure 8

Figure 9

1000
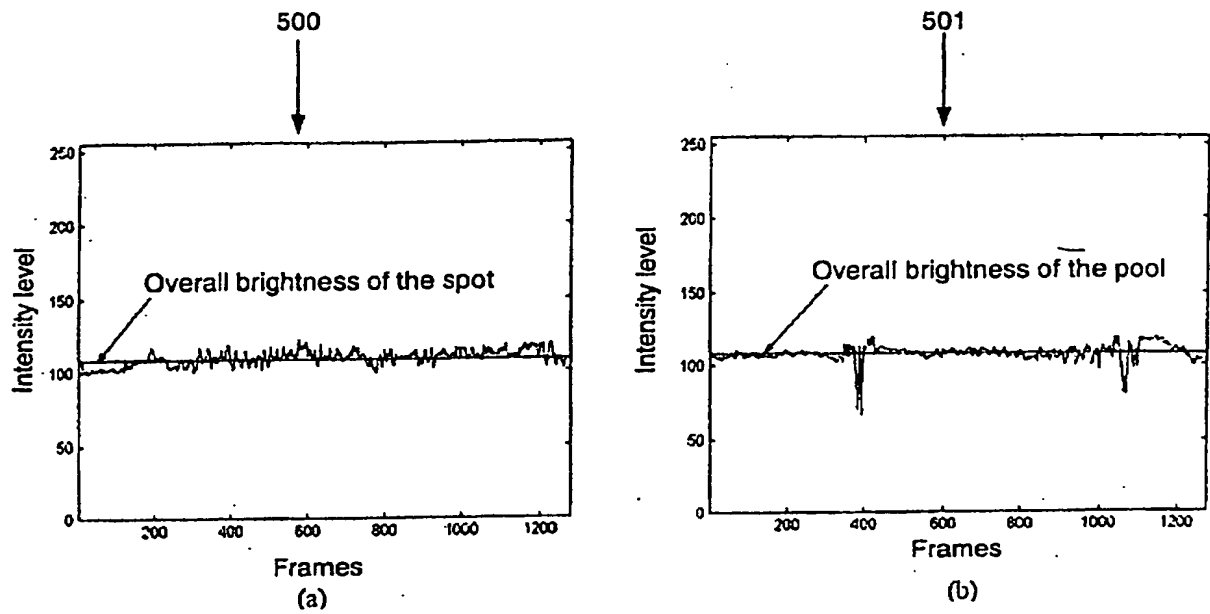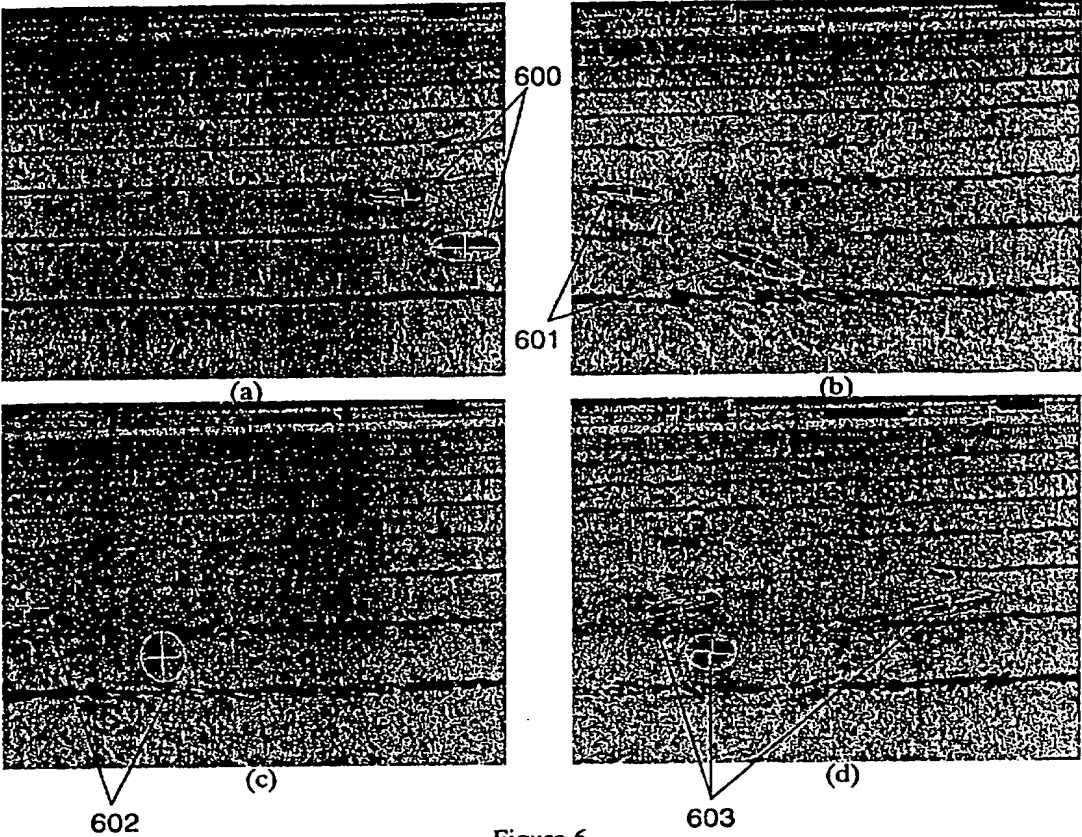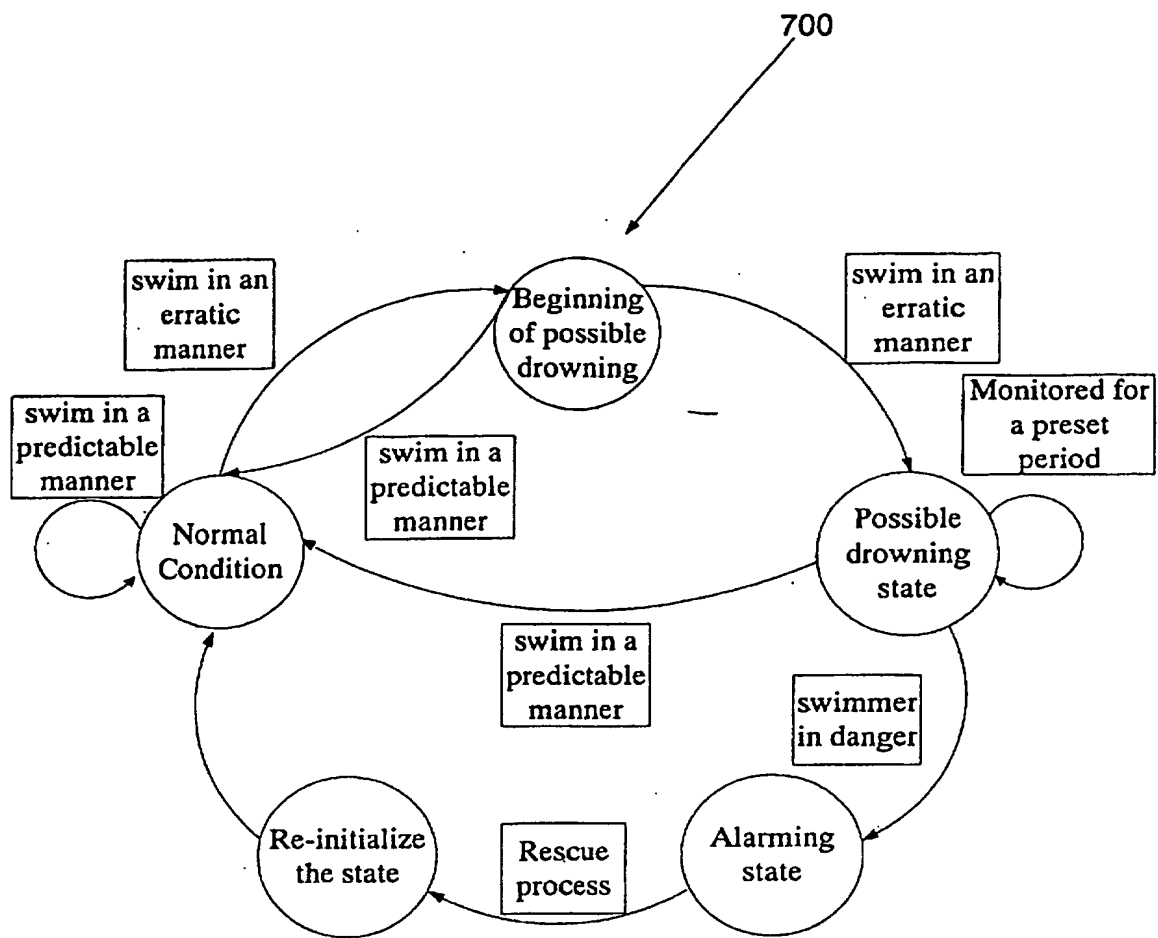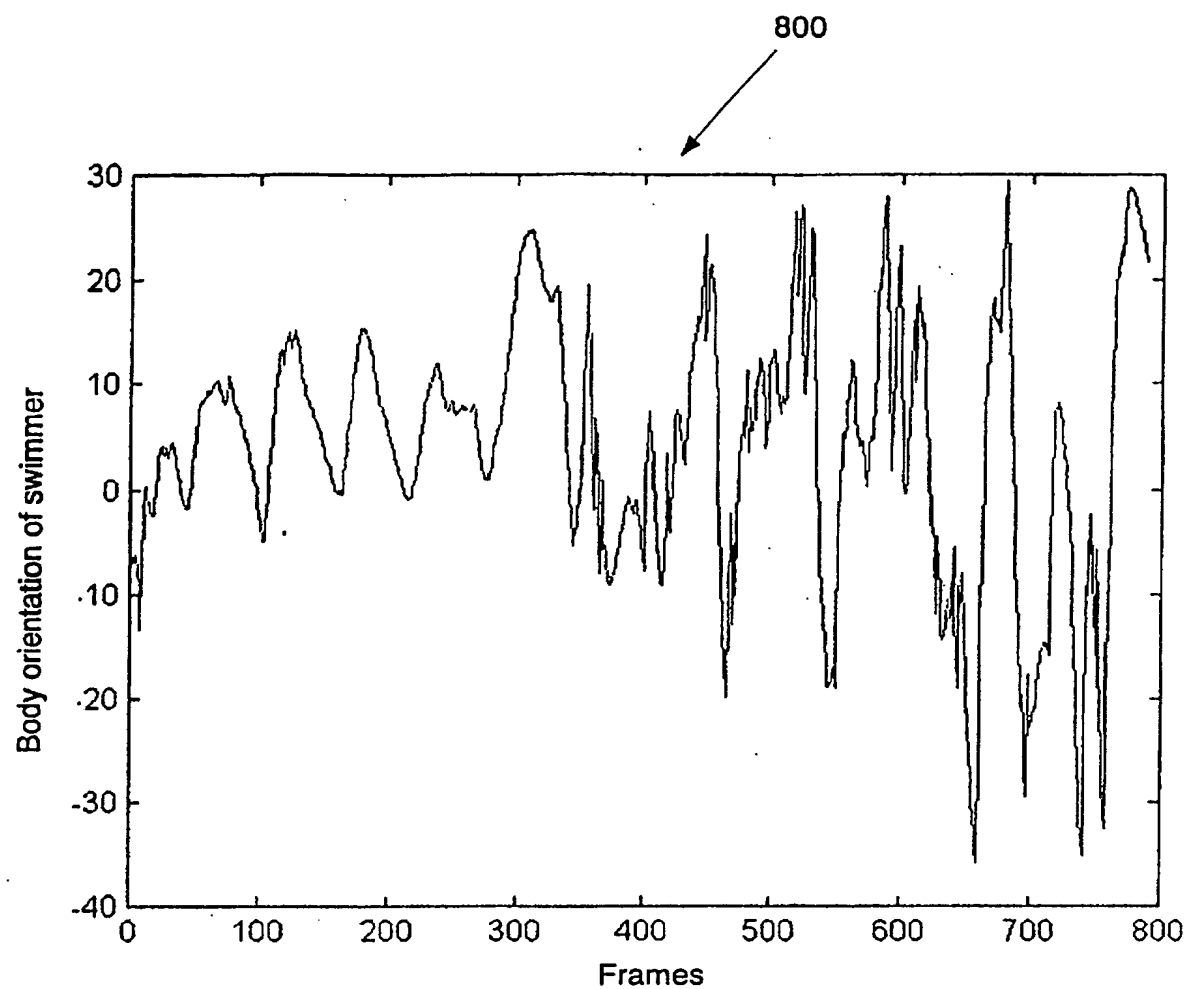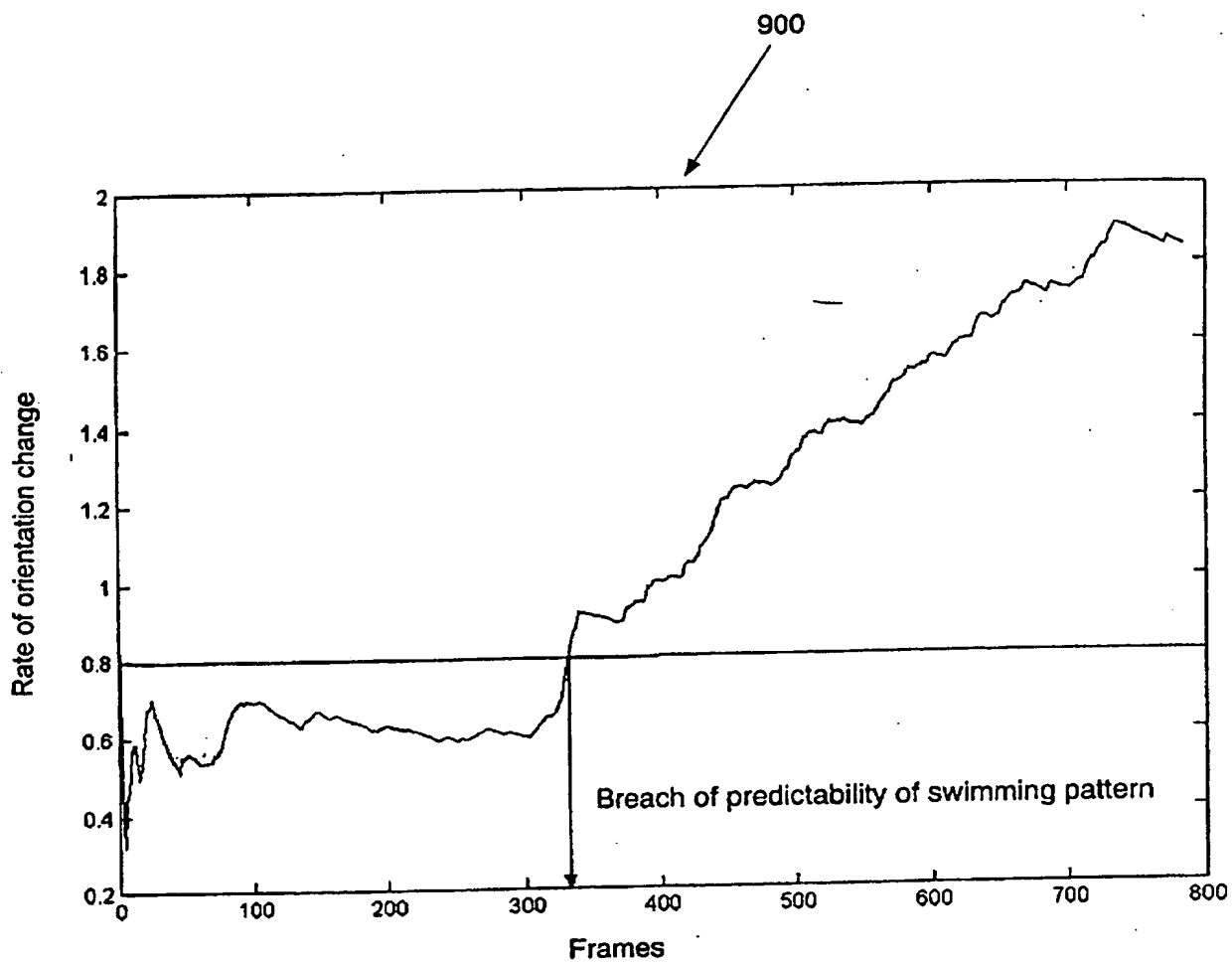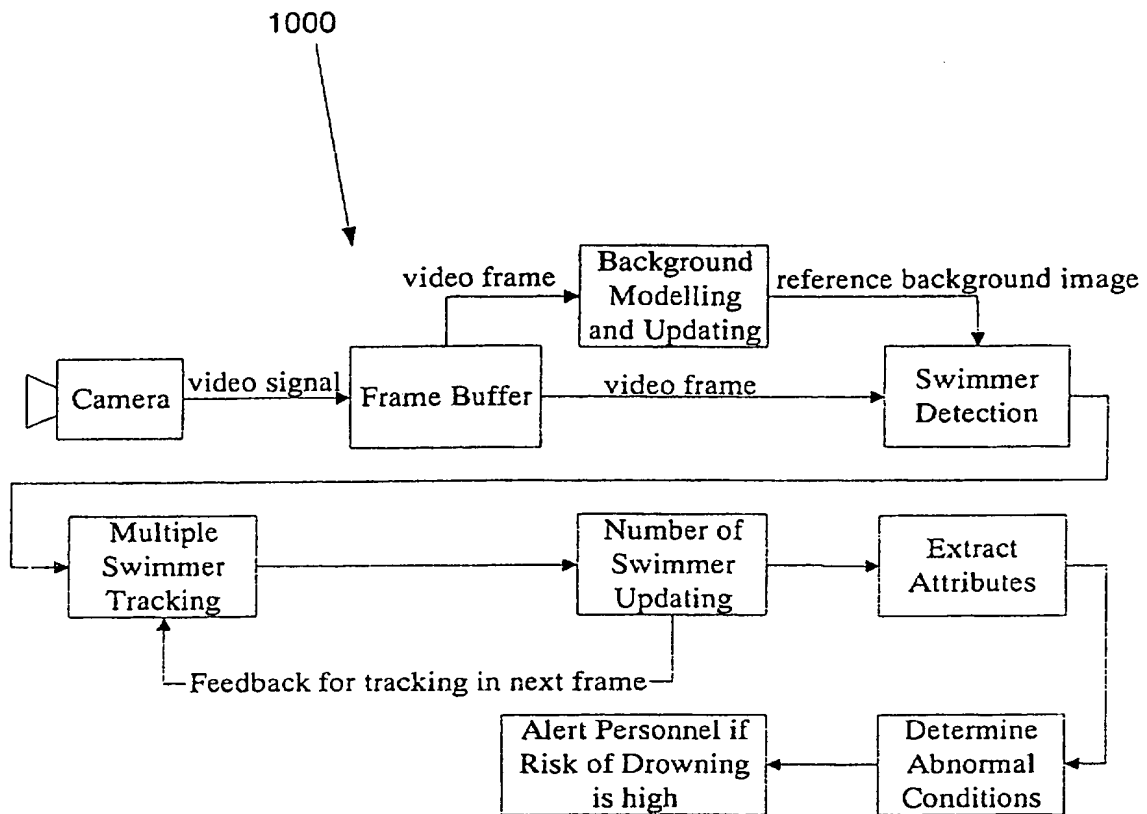
Figure 10

INTERNATIONAL SEARCH REPORT

CLASSIFICATION OF SUBJECT MATTER

IPC[7]: G08B 21/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC[7]: G08B 21/00, G06T 7/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5953439 A (ISHIHARA ET AL.) 14 September 1999 (14.09.99) *abstract, claims, figs.*	1,31,38
A	FR 2763459 A1 (POSEIDON) 20 November 1998 (20.11.98) *abstract, claims, figs.*	1,31,38
P,X	WO 01/46908 A1 (POSEIDON) 28 June 2001 (28.06.01) *the whole document.*	1,31,38

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
„A" document defining the general state of the art which is not considered to be of particular relevance
„E" earlier application or patent but published on or after the international filing date
„L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
„O" document referring to an oral disclosure, use, exhibition or other means
„P" document published prior to the international filing date but later than the priority date claimed

„T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
„X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
„Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
„&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 October 2002 (18.10.2002)	13 November 2002 (13.11.2002)

Name and mailing adress of the ISA/AT **Austrian Patent Office** **Kohlmarkt 8-10; A-1014 Vienna** Facsimile No. 1/53424/535	Authorized officer FELLNER T. Telephone No. 1/53424/345

Form PCT/ISA/210 (second sheet) (July 1998)

Patent document cited in search report			Publication date	Patent family member(s)	Publication date
FR	A1	2763459	20-11-1998	none	
FR	B1	2763459	23-07-1999		
US	A	5953439	14-09-1999	none	
WO	A	146908		none	

PCT/ISA/210 (patent family annex) (July 1998)